

# *Self-Adaptive Discovery Mechanisms for Improved Performance in Fault-Tolerant Networks*

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***Scalable Software for  
Hostile & Volatile Environments***

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## *Presentation Outline*

- One-Page Review of Project Objective and Plan
- One-Page Refresher on Service Discovery Protocols
- Analysis of Jini Leasing Performance
- Self-Adaptive Leasing for Jini
  - Two Algorithms: Simple Adaptive Leasing and Inverted Leasing
  - Performance characteristics (*obtained via simulation*)
- Leasing with Multiple Lookup Services
- Summary of Other Accomplishments Since July 2002
- Plan for Next Six Months
- Conclusions

## *Project Objective*

Research, design, evaluate, and implement self-adaptive mechanisms to improve performance of service discovery protocols for use in fault-tolerant networks.

## *Project Plan – Three Phases*



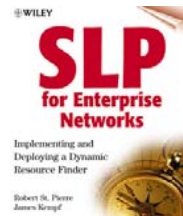



- Phase I – characterize performance of selected service discovery protocols (Universal Plug-and-Play – UPnP – and Jini) as specified and implemented
  - develop simulation models for each protocol
  - establish performance benchmarks based on default or recommended parameter values and on required or most likely implementation of behaviors
- Phase II – design, simulate, and evaluate self-adaptive algorithms to improve performance of discovery protocols regarding selected mechanisms
  - devise algorithms to adjust control parameters and behavior in each protocol
  - simulate performance of each algorithm against benchmark performance
  - select most promising algorithms for further development
- Phase III – implement and validate the most promising algorithms in publicly available reference software

## Dynamic Discovery Protocols in Essence

Dynamic discovery protocols enable *network elements*:

- (1) to *discover* each other without prior arrangement,
- (2) to *express* opportunities for collaboration,
- (3) to *compose* themselves into larger collections that cooperate to meet an application need, and
- (4) to *detect and adapt to changes* in network topology.

## Selected First-Generation Dynamic Discovery Protocols

 <p>3-Party Design</p>	 <p>2-Party Design</p>	 <p>Adaptive 2/3-Party Design</p>
 <p>Vertically Integrated 3-Party Design</p>	 <p>Network-Dependent 3-Party Design</p>	 <p>Bluetooth™ Network-Dependent 2-Party Design</p>

## *A Brief History of Leases in Distributed Systems*

- Originally proposed by Gray and Cheriton for consistency maintenance in distributed file caches [Gray and Cheriton. "Leases: an efficient fault-tolerant mechanism for distributed file cache consistency", *ACM SIGOPS Operating Systems Review*, November 1989.]
- Now widely used in distributed systems
  - Mobile Networking
    - Cao, "On improving the performance of cache invalidation in mobile environments", *Mobile Networks and Applications*, August 2002.
    - Perkins and Luo, "Using DHCP with computers that move", *Wireless Networks*, March 1995.
    - Zheng, Ge, Hou, and Thuel, "A case for mobility support with temporary home agents", *ACM SIGMOBILE Mobile Computing and Communications Review*, January 2002.
  - Distributed File Systems
    - Grönvall, Westerlund, and Pink. "The design of a multicast-based distributed file system", *Proceedings of the third symposium on Operating systems design and implementation*, February 1999
    - Mann, Birrell, Hisgen, Jerian, and Swart. "A coherent distributed file cache with directory write-behind", *ACM Transactions on Computer Systems (TOCS)*, May 1994.
    - Muthitacharoen, Chen, and Mazières. "A low-bandwidth network file system," *ACM SIGOPS Operating Systems Review*, October 2001
    - Thekkath, Mann, and Lee. "Frangipani: a scalable distributed file system", *ACM SIGOPS Operating Systems Review*, October 1997.

## *A Brief History of Leases in Distributed Systems (cont.)*

### ➤ Shared Memory

- Harris and Sarkar. "Lightweight object-oriented shared variables for distributed applications on the Internet", *ACM SIGPLAN Notices*, October 1998.
- Gharachorloo, Gupta, and Hennessy. "Performance evaluation of memory consistency models for shared-memory multiprocessors", *ACM SIGARCH Computer Architecture News*, April 1991.

### ➤ Web Systems

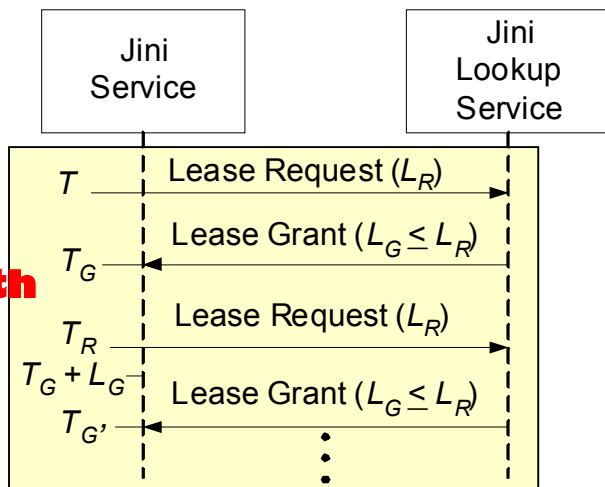
- Ninan, Kulkarni, Shenoy, Ramamritham, and Tewari. "Performance: Cooperative leases: scalable consistency maintenance in content distribution networks", *Proceedings of the eleventh international conference on World Wide Web*, May 2002.
- Jacobsen and Günther. "Middleware for software leasing over the Internet", *Proceedings of the first ACM conference on Electronic commerce*, November 1999.
- Shih and Shim. "A service management framework for M-commerce applications", *Mobile Networks and Applications*, June 2002.

### ➤ Service Discovery Systems

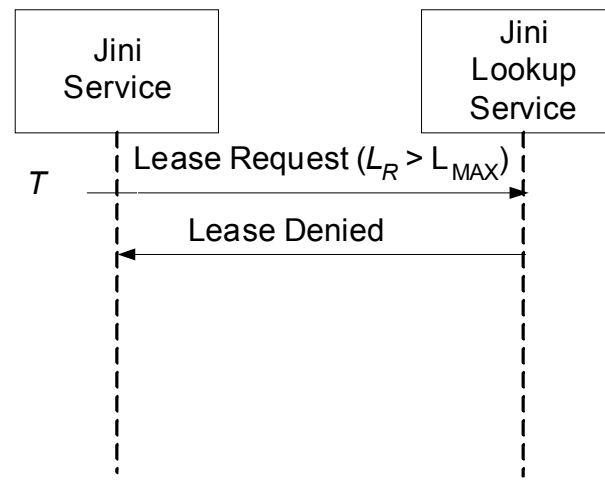
- Friday, Davies, and Catterall. "Supporting service discovery, querying and interaction in ubiquitous computing environments", *Second ACM international workshop on Data engineering for wireless and mobile access*, May 2001.
- Hodes, Czerwinski, Zhao, Joseph, and Katz. "An architecture for secure wide-area service discovery", *Wireless Networks*, March 2002.
- Universal Plug and Play Device Architecture, Version 1.0, 08 Jun 2000 10:41 AM. © 1999–2000 Microsoft Corporation. All rights reserved.
- Waldo. "The Jini architecture for network-centric computing", *Communications of the ACM*, July 1999.

## Selected Jini Leasing Sequences

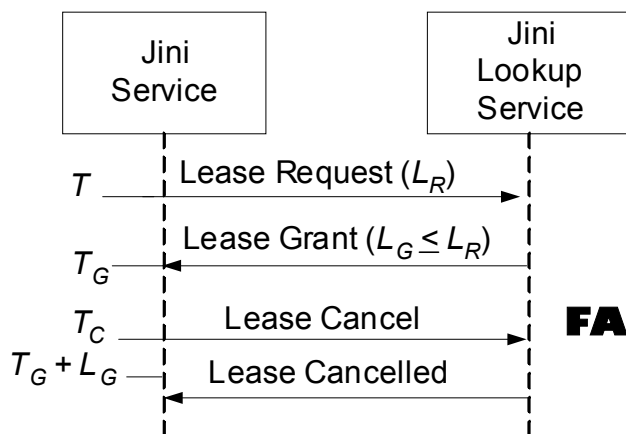
**Bandwidth  
usage**



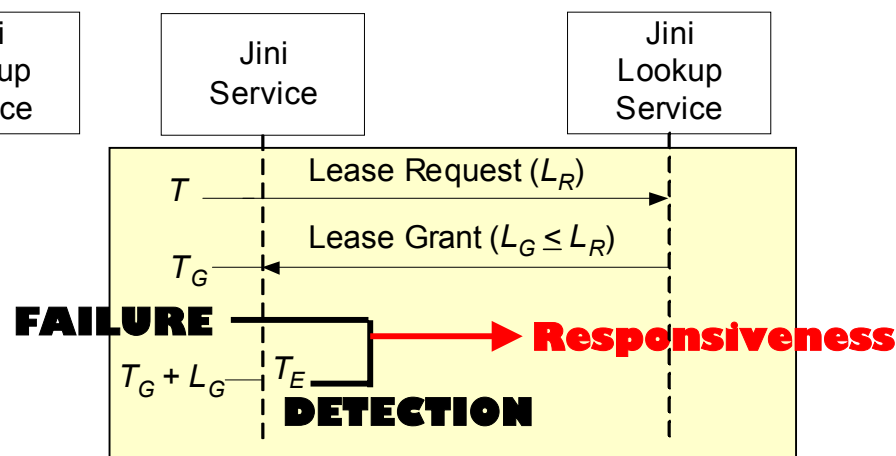
(a) Initial Lease Grant & Renewal



(b) Lease Denial



(c) Lease Cancellation



(d) Lease Expiration



## Analysis of Jini Leasing Performance

Let  $N$  = number of leaseholders,  $S_R$  = size of lease request message, and  $S_G$  = size of lease grant message

Bandwidth Consumption ( $B$ )

$$B = (N / L_G) \cdot (S_R + S_G)$$

Responsiveness ( $R$ )

$$R = L_G / 2$$

Given requirements for  $B$  and  $R$ , what lease period should be granted to each leaseholder and how many leaseholders can be supported?

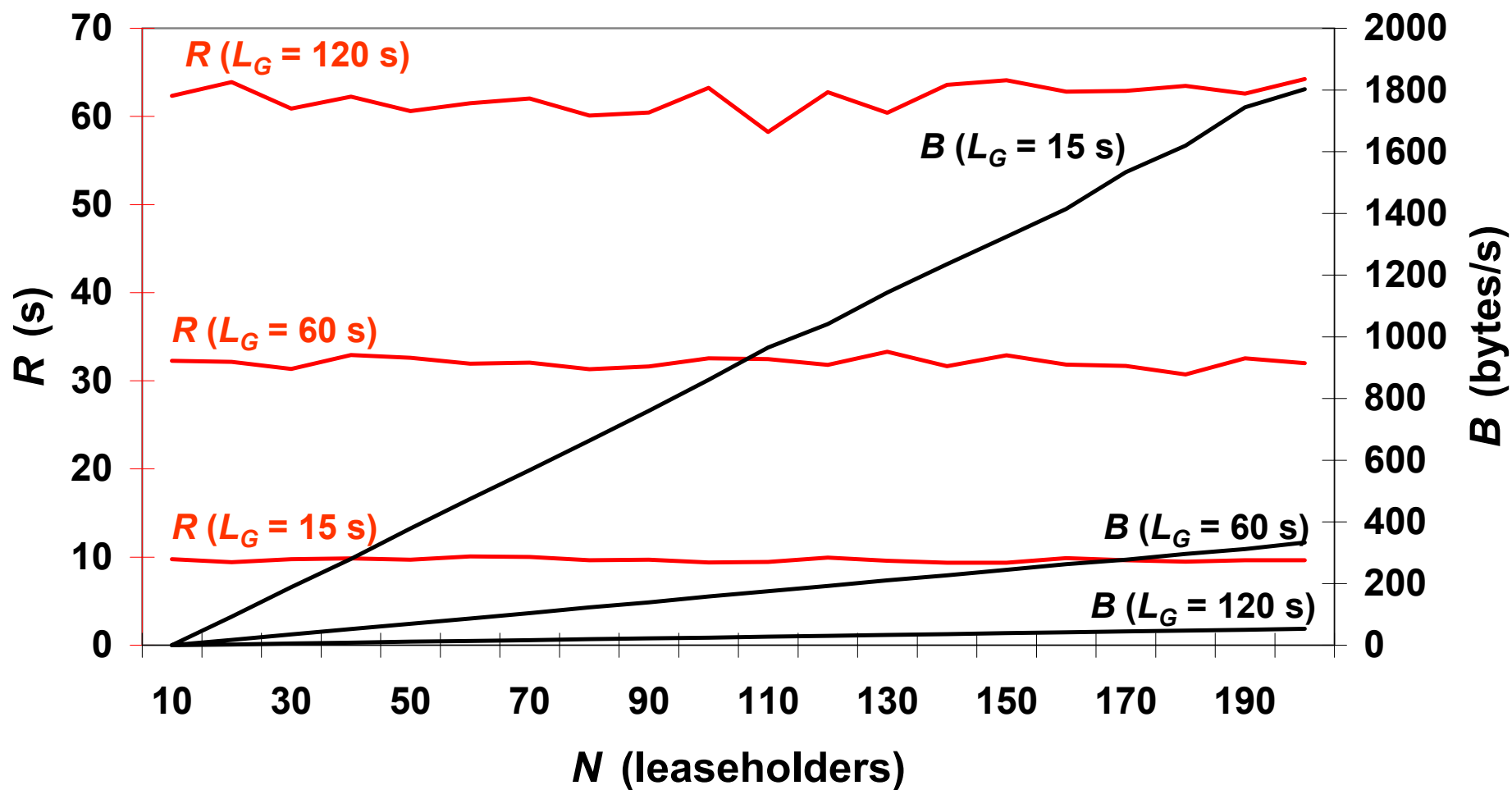
$L_G = 2R$  Re-writing responsiveness equation yields a value for lease period to grant

$N_{MAX} = (B \cdot L_G) / (S_R + S_G)$  Transforming bandwidth equation indicates maximum system capacity

What decisions must the lease grantor make to guarantee  $R$  and  $B$ ?

1. Deny lease requests that would consume excessive bandwidth (*i.e.*, when  $L_R < L_G$ )
2. Grant lease periods no greater than  $L_G$  to ensure desired responsiveness
3. Deny lease requests when the number of leaseholders would exceed capacity (*i.e.*, when  $N = N_{MAX}$ )

## Simulation Results: Responsiveness and Bandwidth Usage vs. Network Size for Various $L_G$ Values



## A Simple Adaptive Leasing Mechanism

**Goal:** limit bandwidth usage to  $B$  and guarantee a minimum responsiveness ( $R_{MIN}$ ), while achieving the best possible responsiveness  $R > R_{MIN}$  when  $N < N_{MAX}$

### Preliminary Analysis

$L_{MAX} = 2R_{MIN}$  Minimum Responsiveness determines maximum granted lease period

$G = B / (S_R + S_G)$  Available bandwidth determines maximum lease renewals per second ( $G$ )

$L_{MIN} = 1 / G$  Assuming minimum system size of 1,  $G$  determines minimum granted lease period

$L_{MIN} = 2R_{MAX}$  However,  $1/G$  might place too great a load on the leaseholder, so instead choose a maximum responsiveness and let that determine the minimum granted lease period

$L_{MIN} \leq L_G \leq L_{MAX}$  Vary the granted lease period within this range, using the following algorithm

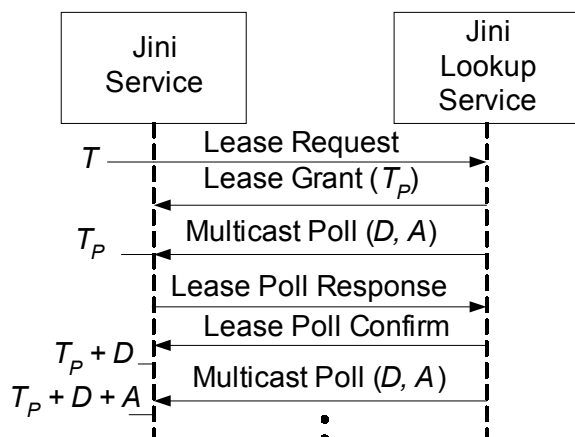
Adaptive Algorithm for Varying  $L_G$

```

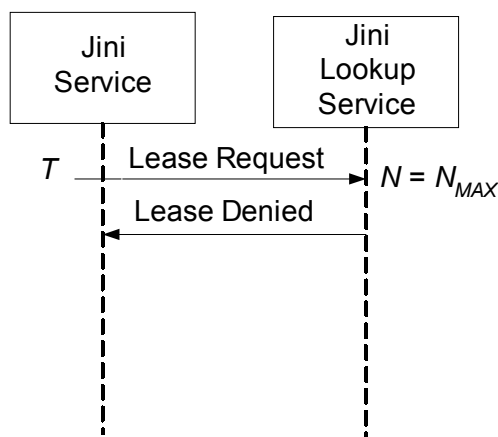
set  $L_G = N / G$ ;
if  $L_G > L_{MAX}$ 
  then deny the lease;
elseif  $L_G < L_{MIN}$ 
  then set  $L_G = L_{MIN}$ ;
endif
endif
  
```

## An Inverted Leasing Mechanism

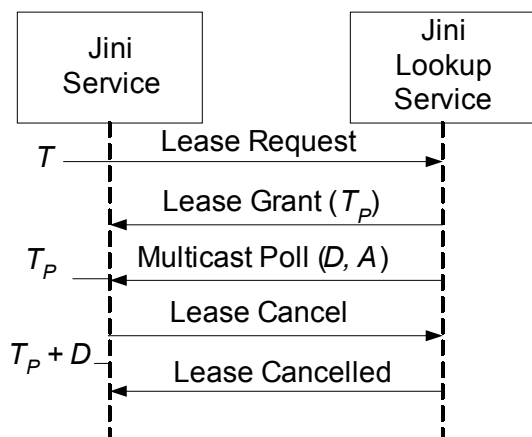
**Main Idea:** lookup service periodically polls leaseholders on a multicast channel – adapting the polling interval to accommodate variations in the number of leaseholders



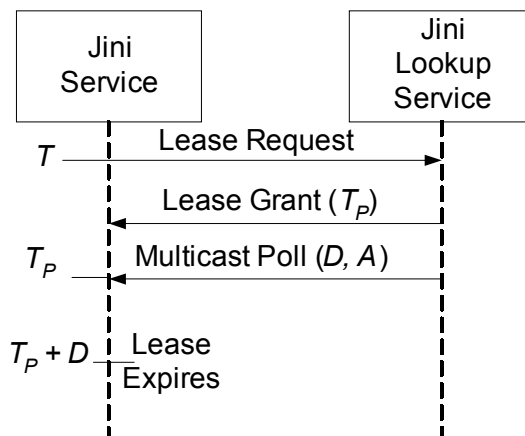
(a) Initial Lease Grant & Renewal



(b) Lease Denial



(c) Lease Cancellation



(d) Lease Expiration

### Polling Interval

Each poll contains the interval ( $D$ ) over which the lookup service listens for responses and an additional time ( $A$ ) within which the next poll will be sent, and

$$L_{MIN} \leq D + A \leq L_{MAX}$$

### Additional Constraint

Grant leases only up to  $N \leq N_{MAX}$ ,  
where  $N_{MAX} = L_{MAX} * G$

## Adaptive Algorithm for Inverted Leasing Mechanism

**Adaptive Algorithm for  
Varying  $D$  (and  $A$ )  
and Selecting  $T_{POLL}$**

```

set  $D = \text{Max} (N / G, L_{MIN})$ ;
set  $A = 0.2 D$ 
if  $D + A > L_{MAX}$ 
    then set  $A = 0$ ;
endif
set  $T_{POLL} = \text{time} + D$ ;
    
```

Since  $N \leq N_{MAX}$ ,  
 $D \leq L_{MAX}$

### Preliminary Analysis

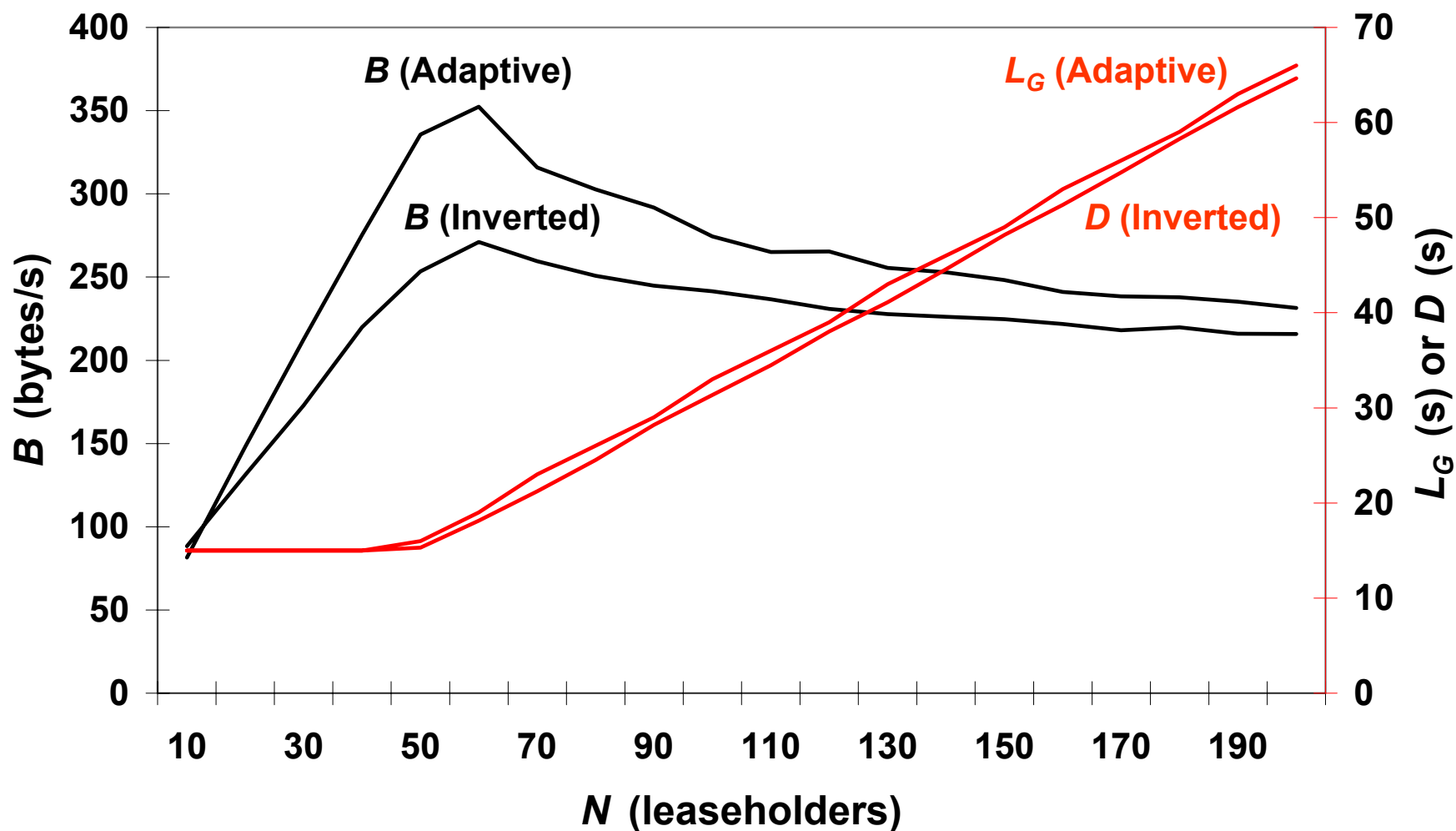
$B = S_P + ((N / P) \cdot (S_{PR} + S_{RC}))$  where  $P$  is the polling interval ( $D \leq P \leq D + A \leq L_{MAX}$ ),  $S_P$  is poll size, and  $S_{PR}$  and  $S_{RC}$  are size of poll response and confirm

Assuming half of failures occur before poll and half after:  $R = 1 / 2 \cdot (D / 2) + 1 / 2 \cdot (3D / 2) = D$

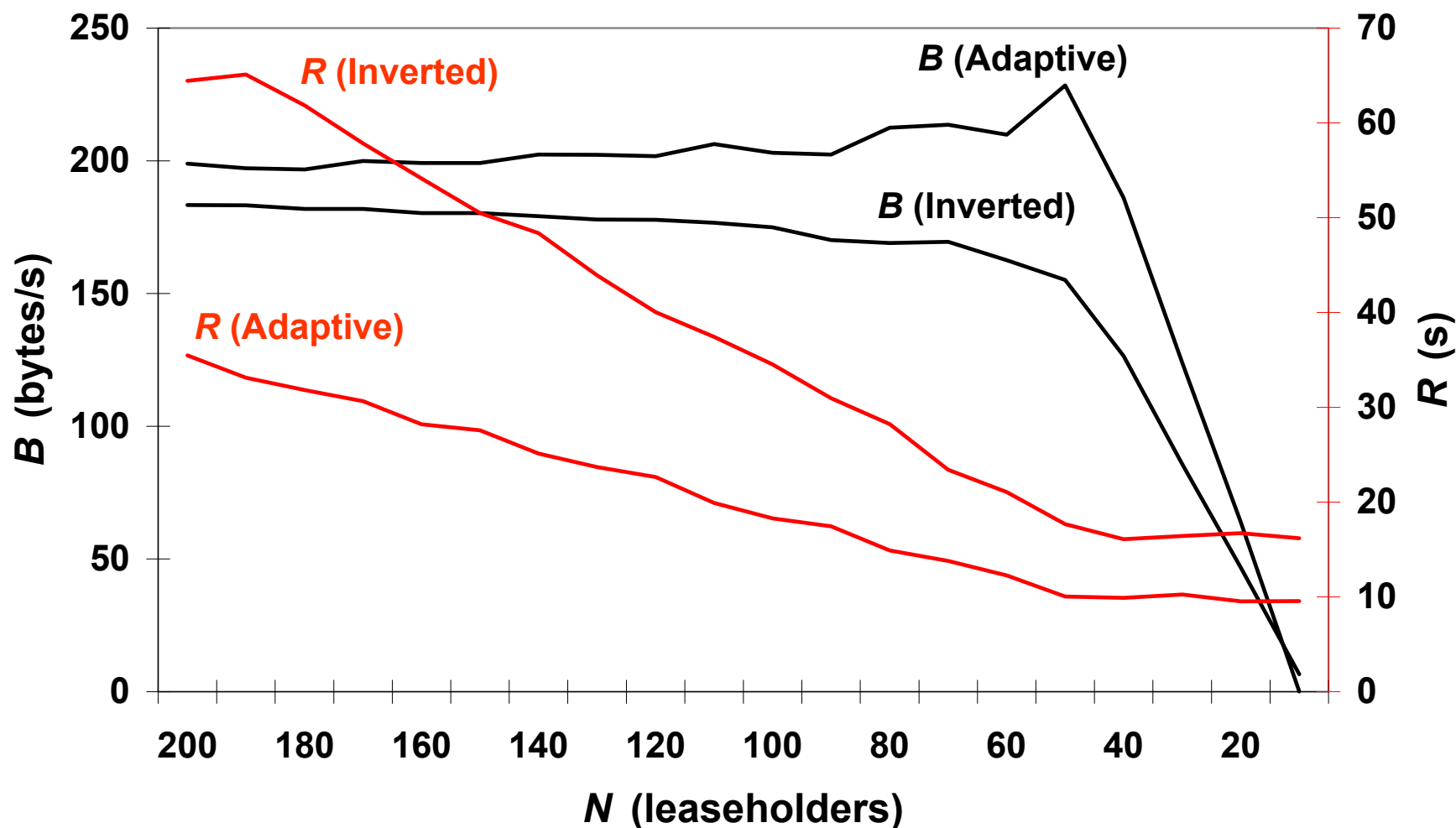
So inverted leasing will be only  $\frac{1}{2}$  as responsive as simple adaptive leasing (recall  $R = L_G / 2$ )

From this result we can also infer that  $R_{MAX} = L_{MIN}$  and  $R_{MIN} = L_{MAX}$

## Bandwidth Usage and Control Variable Value vs. Increasing Network Size for Adaptive and Inverted Leasing Algorithms



## Bandwidth Usage and Responsiveness vs. Decreasing Network Size for Adaptive and Inverted Leasing Algorithms



## *Adaptive Leasing with Multiple Lookup Services*

**Main Goal:** Given a domain-wide limit for leasing resources, expressed either in terms of bandwidth ( $B_D$ ) or renewals per second ( $G_D$ ), the main goal is to allocate a fair share of the resources to each lease grantor within the domain.

- Let  $N_D$  represent the number of lookup services within a domain.
- Assume each Jini lookup service is configured with a network-wide resource budget for leasing (either  $B_D$  or  $G_D$ )
- Each lookup service can compute its share of available resources (either  $B_D / N_D$  or  $G_D / N_D$ ).

**But we need a means to increase and decrease the allocation of resources with changes in  $N_D$**

- Jini facilitates monitoring  $N_D$  by requiring each lookup service to announce itself periodically (every 120 s recommended) on a designated multicast channel.
- Each lookup service can increment  $N_D$  when a new lookup service is heard and can decrement  $N_D$  when an expected announcement is missed.

**Adaptive  
Algorithm  
for  
Varying  $N_D$**

**As  $N_D$  varies, each lookup service can continuously adjust its share of the available domain-wide leasing resources.**



## *Other Accomplishments Since July 2002*

- Produced three papers
  - "Understanding Self-healing in Service Discovery Systems", C. Dabrowski and K. Mills, *Proceedings of ACM SigSoft Workshop on Self-healing Systems*, November 2002, Charleston, SC, pp. 15-20.
  - "Adaptive Jitter Control for UPnP M-Search", K. Mills and C. Dabrowski, accepted by IEEE International Conference on Communications, 2003.
  - "Self-Adaptive Leasing for Jini", K. Bowers, K. Mills, and S. Rose, accepted by IEEE Pervasive Computing (PerCom) 2003 conference.
- Completed characterization of UPnP and Jini behavior in a tactical (multiple sensor-actuator) application during node failure
- Completed scalable (up to 500 nodes) discrete-event simulation model of the Service Location Protocol (SLP)

## *Plan for the Next Six Months*

- Implement our simple self-adaptive leasing in the publicly available Jini reference code distributed by Sun Microsystems – and demonstrate it at the 2003 DARPA Information Survivability Conference and Exposition (DISCEX III) in April (we will show this demonstration again at the summer 2003 FTN PI meeting)
- Characterize the behavior of the service location protocol (SLP) under hostile and volatile conditions – expect a journal paper in 2003 characterizing the performance of Jini, UPnP, and SLP in response to power failure, communication failure, message loss, and node failure
- Formalize a generic model of service-discovery architectures, including structure, behavior, and properties – expect a journal paper in 2003
- Develop an analytical model of the consistency maintenance behavior of Jini and UPnP during communication failure – expect a journal paper
- Investigate self-adaptive mechanisms for inclusion in SLP
- Continue interactions with the Sun Microsystems Jini team; with Microsoft, Intel and the UPnP Forum; and with the IETF SLP group

## *Conclusions*

- Emerging industry discovery protocols exhibit performance characteristics that vary based on parameter settings, network size, and resource availability
- Tuning such dynamic systems cannot rely on manual configuration methods
- We illustrated one case – Jini leasing – where values for granted lease periods interact with system size to determine performance and resource usage
- We proposed two self-adaptive algorithms for Jini leasing, and we investigated relative performance of the algorithms
- We explained how the simple adaptive leasing algorithm could be used in a Jini system with multiple lookup services
- We believe that our simple adaptive leasing algorithm can also be used for UPnP event subscriptions and for SLP service registrations (with some adjustments).
- We have shared our findings with Sun, Microsoft, Intel, the UPnP Forum, and the IETF SLP group